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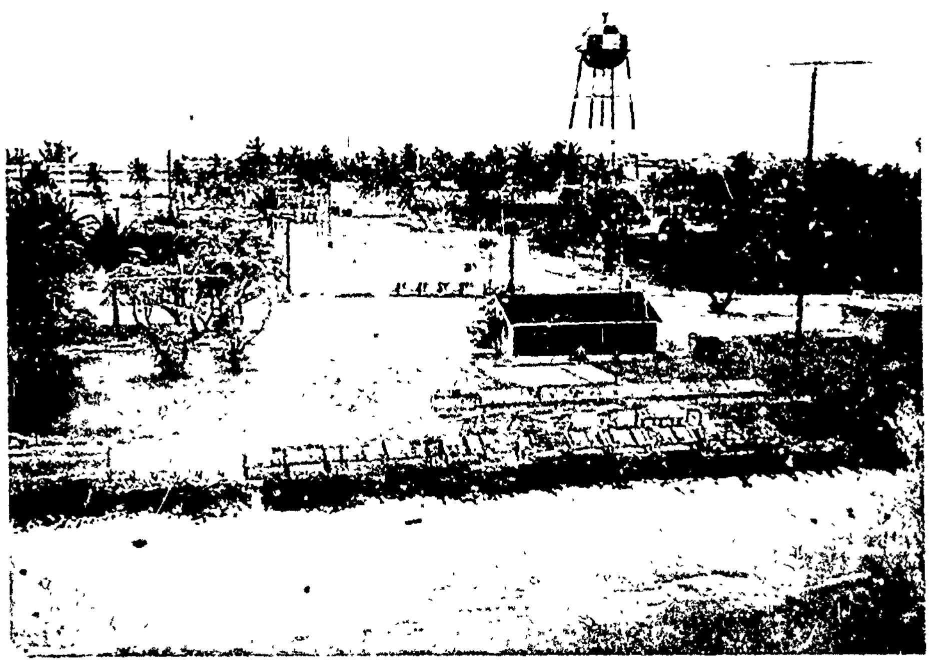

ZINC-RICH ORGANIC SYSTEMS EXPOSED FIVE YEARS TO A MARINE ATMOSPHERE

by Carl V. Brouillette

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ABSTRACT

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INTRODUCTION

This project was originally undertaken by the Naval Civil Engineering Laboratory to provide information on the corrosion resistance of metals exposed to the marine atmospheric environment at Port Hueneme, California. Later, the Naval Facilities Engineering Command (NAVFAC) suggested that this Laboratory and the Materials Testing Branch, Mid-Pacific Construction Division, NAVFAC integrate their separate programs for protective coatings. At that time the scope of the work was modified to emphasize the evaluation of protective coatings in tropical as well as subtropical marine atmospheric environments. Because of the difference in temperature, humidity, solar radiation, and salt spray, simultaneous studies were initiated on identical coatings at Port Hueneme, California (two sites); Kaneohe, Hawaii (two sites); and Kwajalein, Marshall Islands. A standardized rating procedure was established, and the Laboratory sent the first shipment of coated test panels to the Materials Testing Branch, NAVFAC, MIDPAC, in December 1955.

Because of the long-range protection reported possible with zinc-rich coatings and their low toxicity, these coatings have been tested in the three marine atmospheric test locations. In October 1964 steel test panels coated with zinc inorganic silicates, with and without topcoats, were installed at the three sites.[1] In October 1966 zinc-rich organic coatings (epoxies), with and without topcoats, and a selected specification control standard paint system were exposed. In October 1967 a zinc-filled modified saran coating, with and without a topcoat, was exposed with a control standard paint system. This report covers 5 years of exposure for the zinc-rich epoxies and the modified saran. Three years of exposure for the epoxies was reported in Reference 2 and for the saran in Reference 3.

TEST PROCEDURE

Laboratory Analyses

All paint coatings tested were analyzed to determine physical properties and composition. Analyses were based on methods specified in Federal Test Method Standard No. 141; ASTM Standards, Part 21; and Painting

Testing Manual, 12th Ed. by Gardner and Sword. The physical properties determined included weight per gallon, specific gravity, and consistency. Composition analyses were made to determine the amounts of nonvolatile solids, total pigment, nonvolatile vehicle and, where applicable, the amount of ash. Infrared spectra were prepared from the resins and curing agents of the epoxy coatings. Results of the laboratory analyses appear in Appendix A of Reference 2.

Panel Preparation

All test panels coated for exposure tests were mild steel, 6 x 12 x 1/8 inch, giving approximately 1 square foot of area overall. The surface preparation was by sandblasting both sides to a uniform gray mat finish. The panel edges were rounded prior to sandblasting to minimize coating failure at the edges. Twenty panels were prepared for each coating system. The coating systems were applied to both sides of the panel by means of an automatic horizontal transverse paint spraying machine which resulted in uniform paint thicknesses for each set of panels. After being coated, the panels were dried or cured as required for the particular coating.

In order to evaluate loss of adhesion and blistering of a coating associated with corrosion at a break in the coating, and to accelerate the testing procedure, two diagonal cuts were made through the coating to expose the steel substrate. These scribes were made in the shape of an X on one side of the coated test panel and extended to about 1-3/8 inches from each corner.

Four coated test panels, three scribed and one not scribed, were placed in marine atmospheric exposure at each of the five test sites. The scribed panels were exposed with the scribes facing up. However, sometime between the 2- and 3-year inspection period a severe storm completely washed out the lower site at Kaneohe, leaving no trace of test panels or racks. Test comparisons in this report do not include results from this lower level site. Two-year data and test comparisons for this site were reported in References 2 and 3.

The exposed coated panels were inspected annually, at which time photographs were taken and the coating performances were rated. Assigned ratings are tabulated in Appendix A.

EXPOSURE LOCATIONS

The coated test specimens were exposed to the marine atmospheric environments at four exposure sites as follows.

Kwajalein

The exposure racks at Kwajalein are about 75 feet from the surf at high tide and hold the panels facing east-northeast at about a 45-degree angle to the horizontal. The prevailing east-northeast wind continually carries large amounts of salt spray to the panels. This exposure site is near the center of the tropical zone, lying in 8°44' north latitude. Rainfall is plentifull, averaging over 10 inches per month during 8 months of the year; the average daily high temperature is in the 81 to 83°F temperature range.

Kaneohe

The upper level exposure racks at Kaneohe face east-northeast into the prevailing wind and are about 450 feet from the surf. The panels are placed at a 45-degree angle to the horizontal. The wind often carries small amounts of sand and grit, which are slightly abrasive to the face of the panels. This test area is near the northern edge of the tropical zone, being at 21°21' north latitude. (The Tropic of Cancer is at 23°27' north latitude.) The Kaneohe Test Site has very slightly greater variation in temperature than Kwajalein, the average daily high temperature ranging from 73 to 79°F The average monthly rainfall varies from 1 to 9 inches.

Port Hueneme

Site 1 is a mild environment which exposed the test specimens at 45 degrees to the horizontal facing south about 200-500 feet from the surf. The beach is unstable in this area, and the surf line continually changes. The prevailing wind is from the west and very fine salt spray is carried to the test panels.

Site 2 is located on a pier where the test specimens are exposed at a 45-degree angle to the horizontal facing west. The exposure site runs parallel to a rock jetty (breakwater) which is about 300 feet to the west of the pier. The surf breaks against this jetty, and the prevailing west wind continually carries salt spray onto the test specimens.

Port Hueneme is at 34°7' north latitude, which is 10°40' north of the Tropic of Cancer. The total average annual rainfall is about 12 inches, most of which falls between September and March. The average annual temperature range is from 52 to 65°F. The relative humidity is generally high during most of the year.

DESCRIPTION OF COATING SYSTEMS

The zinc-rich test coatings consisted of both proprietary materials and those prepared by adding varying increments of zinc dust to a modified saran obtained from the Paint Laboratory, San Francisco Bay Naval Shipyard.

The proprietary zinc-rich coatings were exposed with and without topcoats of a proprietary coating, a modified silicone alkyd and a specification alkyd. The modified saran containing zinc dust pigmentation was exposed both topcoated with the modified saran and without a topcoat.

The film thicknesses of coating systems described below are given in Appendix B. The coating sources are listed in Appendix D of Reference 2.

Control Standard Coatings

Three coatings were used as control standards: System 9, an alkyd system (MIL-P-15328B pretreatment primer with TT-E-485d rust-inhibiting enamel and TT-P-489c topcoat); and System 11, the MIL-SPEC saran (MIL-L-18389).* A modified saran without zinc dust, System 10 was also applied over sandblasted steel in alternate coats of orange and white for comparison with the MIL-SPEC saran.

Zinc-Rich Coatings Without Topcoats

Five proprietary zinc-rich epoxy coatings and three modified saran zinc-rich coatings, without topcoats, were tested. The five proprietary coatings represented the following: Two one-package zinc-rich epoxy-type coatings which dried by solvent evaporation, Systems 1 and 4;** one amine-cured two-package epoxy coating with zinc dust incorporated in the resin component, System 2; and two coatings with the zinc dust in a separate container which resulted in two amide-cured three-package epoxy coatings, Systems 3 and 5. The modified saran coatings represented three different loadings of zinc dust. System 6 contained 10 pounds of zinc dust per gallon of coating, System 7 contained 5.3 pounds and System 8 contained 3.1 pounds of zinc dust per gallon of the orange modified saran.

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* MIL-L-18389 (ships) Lacquer, Vinylidene Resin, Water and Fuel Resistant, White and Orange. This specification has been canceled by Notice 1, August 25, 1970.

** Analysis showed System 4 conformed to MIL-P-26915A, Type I, Class A, Primer Coating, Zinc Dust Pigmented for Steel Surfaces.

Proprietary Topcoats Over Zinc Rich Coatings

Each proprietary zinc-rich organic coating was also topcoated with a proprietary coating recommended by the supplier. System 1-1 was the zinc-rich epoxy of System 1, an intermediate coat of amide-cured coal-tar epoxy, and a topcoat of an aluminum-filled bituminous emulsion. System 2-1 was an amine-cured epoxy applied over the zinc-rich epoxy of System 2. In like manner, System 3-1 had a topcoat of an aluminum-filled coal-tar epoxy, System 4-1 had a topcoat of a one-package epoxy, and System 5-1 had an amide-cured epoxy topcoat.

The zinc-rich modified orange saran, Systems 6, 7 and 8, were topcoated with modified white saran and designated Systems 6-1, 7-1, and 8-1, respectively.

Alkyd Topcoats Over the Zinc-Rich Coatings

The alkyd enamel, TT-E-489c, was applied in two coats as a test topcoat over the zinc-rich coatings of Systems 1, 3, 4, and 5 as Systems 1A, 3A, 4A, and 5A, respectively. System 2A consisted of the zinc-rich coating of System 2 with an intermediate coat of TT-E-485d rust-inhibiting enamel and a topcoat of TT-E-489c alkyd enamel. Systems 3A-1 and 4A-1 represented the zinc-rich coatings of Systems 3 and 4, respectively, topcoated with the alkyd enamel system, MIL-P-15328B pretreatment primer, TT-E-485d rust-inhibiting enamel, and TT-E-489c enamel topcoat.

Silicone Alkyd Topcoat Over Zinc-Rich Coatings

Systems 1SC, 2SC, 3SC, 4SC and 5SC represented the zinc-rich coatings of Systems 1, 2, 3, 4 and 5, respectively, topcoated with a silicone alkyd over TT-E-489c as a tie coat. The silicone alkyd coating (Mare Island Formula 1005; Table 1 of Reference 2) is similar to MIL-P-15130, but modified to incorporate a silicone alkyd resin solution in place of the alkyd resin solution, TT-R-266.

Modified Saran Topcoats Over Zinc Filled Modified Saran

The modified saran, formulated by the Paint Laboratory, San Francisco Bay Naval Shipyard, was equivalent to the Navy saran (MIL-L-18389) in resin and pigmentation but utilized a higher flash point solvent which reduced its potential as a fire hazard. Also, the tendency to "cobweb" during application was lessened, and leveling and film forming properties were improved. The addition of zinc dust to the modified orange saran permitted application of a 2-mil (0.002-inch) dry film thickness per coat, as compared to 1 mil per coat obtained without the zinc dust pigmentation. Systems 6S, 7S, and 8S contained zinc dust in the orange primer coat. The topcoats were white modified saran without zinc.

Figure 1. System 9, alkyd control standard after 2 years of exposure at Kwajalein.

EXPOSURE TEST RESULTS

Control Standard Coatings

The alkyd (System 9, the overall test control standard) failed along the scribe in Kwajalein between 1 and 2 years (Figure 1), in Kaneohe during 3 years, and in Port Hueneme Site 2 during 4 years of exposure. At Site 1 in Port Hueneme the scribed panel was receiving excellent protection (rating 10*) after 5 years of exposure. Because there was rusting and blistering only at the edges after 4 years of exposure, the protection of the unscribed panel of System 9 was considered good (rating 9) in Kwajalein. At Kaneohe the unscribed panel was receiving very good protection, and at Port Hueneme Sites 1 and 2 the unscribed panel was receiving excellent protection after 5 years of exposure. The scribed panels of the MIL-SPEC saran (System 11) failed in Kwajalein and Kaneohe during the second year of exposure (Figure 2) and in Port Hueneme Site 2 during the fourth year of exposure. This panel was lost from the Site 1 test rack in Port Hueneme during the first year of exposure. The unscribed panels after 5 years of exposure were receiving very

* Rating procedure described in Appendix A.

good protection (rating 9+) in Kwajalein and excellent protection in Kaneohe and Port Hueneme. The modified saran, System 10, failed to protect along the scribe in Kwajalein after 3 years of exposure (Figure 3); after 5 years the protection given by this system in Kaneohe was fair (rating 8) and in Port Hueneme Site 2 the protection was good (rating 9). This system was missing at Site 1 after 1 year. The unscribed panels of System 10 were all receiving excellent protection (rating 10) after 5 years of exposure at each test site.

Thus the modified saran, System 10, gave the best protection of the three control systems. The MIL-SPEC saran (System 11) and the standard alkyd control (System 9) gave comparable protection during 4 years of exposure. Failure of the control systems was primarily by blistering along the scribe. The corrosion inhibiting pigments in the alkyd control coating (System 9) were unable to prevent failure along the scribe beyond about 1.5 years in Kwajalein. The saran coatings contain no corrosion-inhibiting pigments but the saran resin paint film is very impervious to water or moisture transmission and protects by preventing moisture from reaching the steel substrate. The modified saran (System 10) was very easy to apply without "cobwebbing."

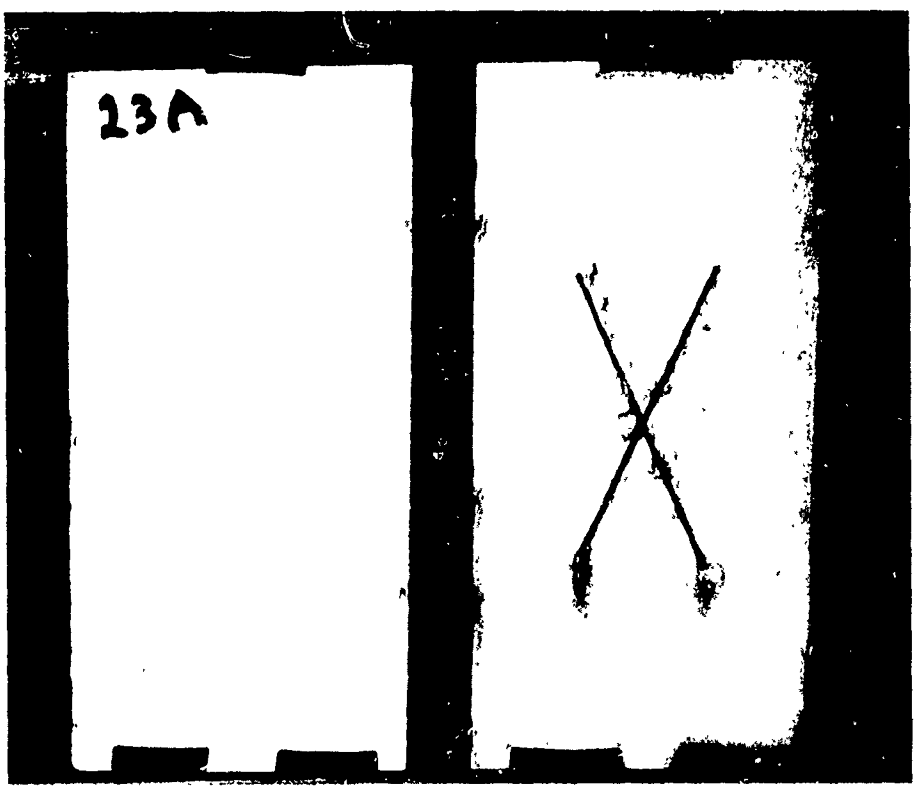

Figure 2. System 11, saran coating (MIL-L-18389) comparison control after 2 years at Kwajalein.

Figure 3. System 10, modified saran (3F-116-1, 3F-116-4) after 3 years of exposure at Kwajalein.

Zinc-Rich Coatings Without Topcoats

After 5 years of exposure at the four test site, the zinc-rich modified saran coatings, Systems 7 and 8, (containing 5.3 pounds and 3.1 pounds of zinc dust per gallon, respectively) were giving good to excellent protection to both the scribed and unscribed test panels at each test site (Figure 4). The primary deterioration observed was an occasional small blister along the scribe in Kwajalein. System 6, containing 10 pounds of zinc dust per gallon, failed at Kwajalein between 2 and 3 years of exposure and in Kaneohe during 3 years for the scribed panel and 5 years for the unscribed panel. At Port Hueneme, System 6 gave excellent protection to both types of panels for 5 years. In both of the tropical environments, Kwajalein and Kaneohe, failure of System 6 was caused by rapid oxidation of the zinc dust. There did not appear to be enough saran resin to completely bond the zinc dust particles together.

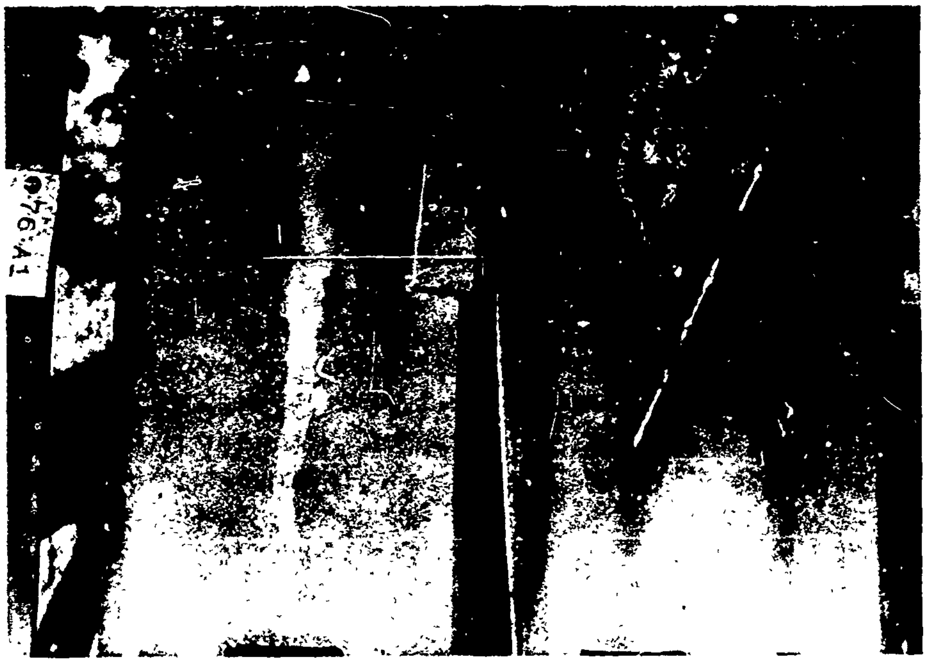

Figure 4. System 8, zinc-rich modified saran (3.1 pounds zinc per gallon) after 5 years of exposure at Kwajalein.

System 2, a two-package coating, and System 3, a three-package coating, gave the best protection of the five zinc-rich epoxy coatings. The only failures during 5 years of exposure were with the scribed panels at Kwajalein during 4 years and at Kaneohe during 5 years of exposure. However, the unscribed panels in Kwajalein were near failure after 5 years. System 5, a three-package epoxy, was considered a very good coating; the scribed and unscribed panels failed during 4 years of exposure in Kwajalein and the scribed panel during 4 years in Kaneohe. The single package zinc-rich coatings, Systems 1 and 4, were only fair coatings and failed to protect both the scribed and unscribed panels between 3 and 5 years of exposure at both the tropical exposure sites. However, in Port Hueneme at both Sites 1 and 2, the protection was good to excellent for both the scribed and unscribed panels during 5 years of exposure.

Systems 2 and 3 gave superior protection compared to the control coating, System 9; System 5 was about equivalent to the control coating and Systems 1 and 4 were slightly inferior. Systems 7 and 8 gave outstanding

protection to the scribed and unscribed steel test panels at all test sites for 5 years and were much superior to the control coatings, Systems 9, 10, and 11.

Proprietary Topcoats Over Zinc-Rich Epoxy Coatings

System 2-1, a two-package, amine-cured, zinc-rich epoxy with an amine-cured epoxy topcoat gave good to excellent protection to the scribed and unscribed panels for 5 years exposure at each test site except for the scribed panel at Kwajalein which failed because of blistering along the scribe during 4 years, Figure 5. System 4-1, a single-package zinc-rich epoxy primer and single-package epoxy topcoat failed only at Kwajalein during 4 years of exposure because of blistering and rusting along the edges and blistering along the scribe; after 5 years of exposure the protection was generally good at Kaneohe and Port Hueneme. Although System 1-1 had a total dry film thickness of 26.0 mils, this system had essentially failed at Kwajalein and Kaneohe during 4 years of exposure because of blistering, rusting and undercutting along the edges. Because of the coating thickness, this system gave excellent protection for over 2 years. System 3-1, a three-package zinc-rich epoxy with an aluminum—coal-tar epoxy topcoat and System 5-1, a three-package zinc-rich epoxy with an epoxy topcoat, failed rapidly along the scribe at Kwajalein and Kaneohe. System 3-1 also failed during 2 years of exposure at Port Hueneme Site 2.

In comparison with control System 9, System 3-1 was inferior, System 5-1 was about equal, and Systems 2-1, 4-1 and 1-1 were superior in protection of the steel specimens.

Alkyd Enamel Topcoats Over Zinc-Rich Epoxy Coatings

The systems designated 1A, 3A, 4A, and 5A represent the alkyd enamel (TT-E-489c) applied directly over the zinc-rich materials of Systems 1, 3, 4, and 5. System 2A utilized a rust-inhibiting enamel (TT-E-485d) over the zinc coating with an enamel (TT-E-489c) topcoat In Systems 3A-1 and 4A-1, the pretreatment primer, MIL-P-15328B, was applied prior to application of the rust-inhibiting enamel and enamel topcoat.

System 4A was slightly the best of the enamel topcoated zinc-rich epoxy primers. The scribed panel failed in Kwajalein during 5 years of exposure, but this system was giving good to excellent protection to the scribed and unscribed panels at the remaining exposure sites. Systems 2A and 3A had failed along the scribe in Kwajalein during 5 years of exposure. The unscribed panel of System 2A was receiving very good protection (rating

of 9+) and the unscribed panel of System 3A was receiving fair protection (rating of 8) in Kwajalein after 5 years of exposure. Good to excellent protection was being given by these two systems to the remaining scribed and unscribed panels in Kaneohe and Port Hueneme after 5 years of exposure.

Figure 5. System 2-1, zinc-rich epoxy with amine cured epoxy topcoat after 4 years of exposure at Kwajalein.

Systems 3A-1 and 4A-1 were affording slightly less protection to steel test panels, especially at Kwajalein and Kaneohe, than were Systems 3A and 4A, respectively. Apparently the wash primer and red-lead primer lessened the protection when used with the alkyd enamel topcoat applied over zinc-rich epoxy primers.

Compared with the control standard System 9, System 1A gave poorer protection to the steel panels, System 5A gave about equal protection, and Systems 2A, 3A and 4A gave much better protection.

Silicone Alkyd Topcoats Over Zinc-Rich Epoxy Primers

The scribed panels of Systems 1SC and 5SC failed in Kwajalein during 4 and 3 years of exposure, respectively. The unscribed panel of System 1SC was receiving fair protection (rating 8E), but there was rusting and blistering along the edges. The remaining panels of these two systems and all panels of Systems 2SC, 3SC (Figures 6, 7) and 4SC, scribed and unscribed at each test site, are receiving good to excellent protection (rating 9 to 10). The silicone alkyd topcoat has exceptionally improved the protective qualities of the zinc-rich epoxy-alkyd coating systems. As stated above, only two scribed panels, both at Kwajalein, in this series have failed, with all remaining panels receiving exceptionally good protection after 5 years.

Modified Saran Topcoat

System 7S (Figure 8) gave better protection to steel in the tropical environments of Kaneohe and Kwajalein than did Systems 6S or 8S but less protection than System 8 which had no modified saran topcoat. The zinc-rich modified saran primer of this system contained 5.3 pounds of zinc dust per gallon of coating. The modified saran used in the primer and as the topcoat was formulated at the Mare Island Naval Shipyard by incorporating higher flash solvents into the specification coating MIL-L-18389. The Mare Island designation for this coating is Formulation 3F-116-1 orange and 3F-116-4 white. This formulation does not tend to cobweb during application, and poses less flash hazard than the specification coatings.

System 8S gave protection equal to the control coating, System 9. System 7S gave much better protection and System 6S only slightly better protection than the control coating. The modified saran topcoat improved the performance of System 6; however, System 8 gave less protection when topcoated with the modified saran.

DISCUSSION

Individual Coating Performance

Zinc-rich coatings without topcoats can develop minute to very evident bulges in the coating surface during exposure.[4] This phenomenon was observed in the zinc-rich inorganic coatings after various periods of exposure.[1] These bulges were found to contain an excess of zinc dust and were found more often in the applied one- and two-package zinc-rich organic

films. When the dense zinc dust and the resin component are mixed and packaged in the same container, the zinc dust will settle to the bottom of the container on storage. After several months of storage the zinc dust is very difficult to completely disperse prior to application. When the zinc dust is packaged separately, as in the three-package coatings (zinc-resin-catalyst, Systems 3 and 5), satisfactory mixing is a lesser problem, and no large bulges were observed with these coatings. During exposure, the agglomerates of zinc dust swell into bulges of zinc corrosion products resembling blisters and initiate early coating failure, resulting in pin-point rusting, flaking and undercutting. Topcoats tended to reduce the incidence of formation of these bulges.[5]

Figure 6. System 2SC, two-package zinc-rich epoxy with silicone–alkyd topcoat exposed 5 years at Kwajalein.

Two zinc-rich modified saran systems, Systems 7 and 8, gave outstanding protection to steel test specimens for 5 years in the tropical environments of Kwajalein and Kaneohe, as well as in Port Hueneme. The only other coatings that gave this type of protection during this 5-year test period were three zinc-rich epoxy primers with a silicone alkyd topcoat, Systems 2SC, 3SC, and 4SC. Coatings which failed only along the scribe

in Kwajalein and consequently were considered exceptionally good coating systems were (1) the silicone alkyd topcoated Systems 1SC and 5SC; (2) the modified saran topcoated Systems 6S and 7S; (3) the specification alkyd enamel topcoated Systems 2A, 3A and 4A; (4) the amine-cured, epoxy-topcoated System 2-1; and (5) the zinc-rich epoxy primers, Systems 2 and 3.

Thus 15 coating systems, using zinc-rich organic resin primers, with and without topcoats, were found to give exceptional to outstanding protection to steel in severe marine atmospheric exposures. The best performance was demonstrated by the silicone alkyd topcoats applied over the five proprietary zinc-rich epoxy primers.

Comparison of the performance of Systems 3A and 4A with that of Systems 3A-1 and 4A-1 indicates that the alkyd enamel gives better protection without the use of a wash primer (Formula 117) or alkyd primer (TT-E-485). In general, the topcoats without a rust inhibiting intermediate coat gave the best protection and improved the performance of a zinc-rich coating, especially if the zinc coating had a tendency to fail because of zinc bulges, as observed in System 4.[4] However, an adverse effect was observed when an aluminum-filled topcoat was applied directly over a zinc-rich primer. System 3-1 (aluminum-filled coal-tar epoxy topcoat over the zinc-rich epoxy primer) failed along the scribe within 1 year at Kwajalein and 2 years at Kaneohe and Port Hueneme. However, System 1-1 (an aluminum-filled bituminous emulsion over a coal-tar epoxy intermediate coat) was giving excellent protection along the scribe during 3 years of exposure in Kwajalein and Kaneohe. Near failure of this system during the fourth year was from rusting and undercutting along the edges. In the case of System 3-1, the aluminum-filled topcoat was in intimate contact with the zinc-rich primer, which was directly over the sandblasted steel surface. Modification of zinc dust pigmentation in a coating by addition of aluminum powder has been found to be deleterious.[4] The failure along the scribe of System 3-1 was probably caused by the zinc functioning as anode between iron and aluminum in the wet salt spray environment. However, this type of deterioration did not occur when this same system (System 3-1) was exposed for 6 months in the deep ocean.[6]

Between 3.1 and 5.3 pounds of zinc dust per gallon in the modified saran appears to be optimum. Both Systems 7 and 8 gave excellent protection during 5 years at each test site, both to the scribed and unscribed panels. However, the modified saran with 10 pounds of zinc dust per gallon, System 6, failed during 3 years at both Kwajalein and Kaneohe. System 8S containing 3.1 pounds of zinc dust per gallon in the primer failed similarly.

The silicone alkyd was the most outstanding topcoat applied over the zinc-rich epoxy primers. Failures which were observed when using the alkyd enamel or proprietary topcoats were not observed when using the silicone alkyd as the topcoat.

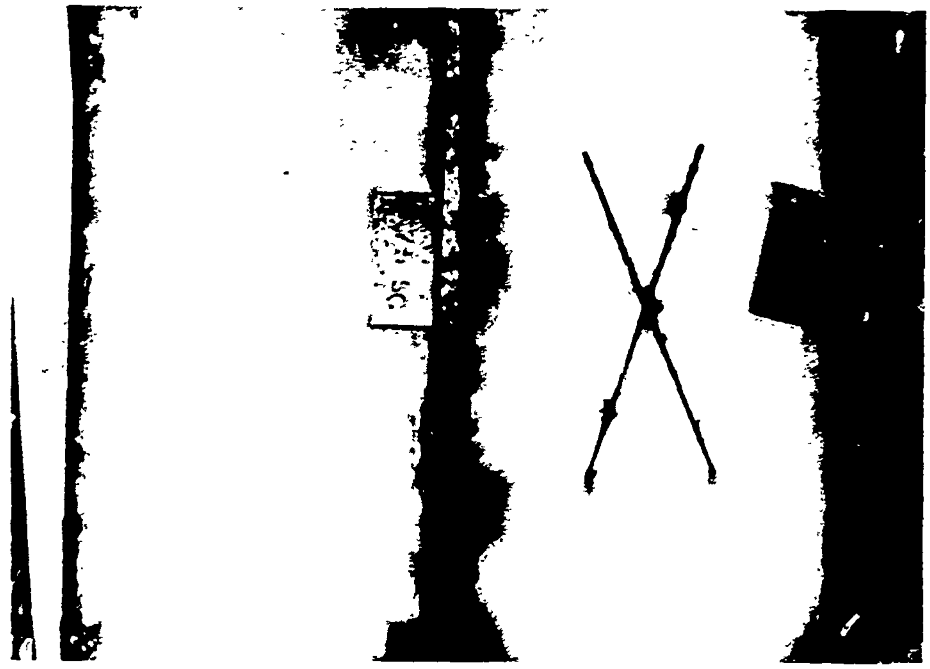

Figure 7. System 3SC, three-package zinc-rich epoxy with silicone–alkyd topcoat exposed 5 years at Kwajalein.

Figure 8. System 7S, zinc-rich modified saran (5.1 pounds zinc per gallon) with a modified saran topcoat after 5 years of exposure at Kwajalein.

Both of the two one-package zinc-rich coatings, System 1 and System 4 (which conformed to MIL-P-26915A, Type I, Class A, Primer Coating), gave poor protection without the benefit of a topcoat. However, System 4 topcoated with the alkyd enamel (System 4A), the silicone alkyd (System 4SC) or the one-package epoxy (System 4-1) gave very good protection during 5 years of exposure at each test site.

The two- and three-package zinc-rich epoxy primers were superior to the one-package zinc-rich epoxy primers and in general gave good protection to the steel test panels. With the alkyd enamel or silicone alkyd topcoats the protection to the steel panels was good for the 5-year exposure period. The control coating, System 9, and the specification saran, System 11, were about equal with failures along the scribe at Kwajalein and Kaneohe in 3 years or less. However, the modified saran, System 10, except for the scribed panel in Kwajalein, gave generally good to excellent protection for 5 years at each test site.

Coating Selection From Tropical Exposure Data

As previously stated, both Kwajalein and Kaneohe are tropical environments, Kwajalein being near the center and Kaneohe being near the northern edge of this zone. As shown by the performance of individual coating systems at these sites, the deterioration of a coating and time to failure to protect the steel substrate are accelerated when compared to a temperate or subtropical climate such as found at Port Hueneme. This acceleration was more pronounced at Kwajalein than at Kaneohe. Reference to Appendix A will show that 31 coating systems, including control coatings, were placed in these three marine atmospheric environments for exposure periods of up to 5 years. At Kwajalein after 3 years, 20 of these 31 coatings were giving satisfactory protection to the steel substrate. Similarly, at Kaneohe 24 coatings were giving satisfactory protection after 3 years of exposure. This shows four coatings that failed at Kwajalein had not yet failed at Kaneohe after 3 years of exposure. Thus, seven and possibly 11 coatings were found to deteriorate rapidly within 3 years and could not be recommended for use in a tropical environment. After 5 years of exposure, only five coating systems were giving acceptable protection at Kwajalein, whereas 19 were continuing to protect at Kaneohe. Also, there were nine coating systems (of the above 20) in this set of tests that were giving excellent protection (rating of 9+ to 10) after 3 years of exposure at Kwajalein. Of these, five (or 56%) were still giving good protection there after 5 years, but it would not have been possible to predict on the basis of ratings at the end of 3 years of exposure which four of these nine systems would fail in the next 2 years. For comparison, at

Kaneohe, 19 coating systems were giving satisfactory protection after 5 years of exposure. Thus, 14 of these 19 had failed at Kwajalein between 3 and 5 years. By comparing the performance of a coating system between 3 to 5 years of exposure at these two tropical marine atmospheric sites a rule of thumb can be postulated for selection of a satisfactory coating system:[7] *For the generic type coating systems of this report, 3 years of exposure at Kaneohe and Kwajalein will eliminate inferior coating systems. After 5 years only the most superior coating systems will continue to give satisfactory protection to the steel test specimens at Kwajalein.* The coatings which fail during these 2 years can be ranked in protective qualities depending on whether they fail at the 4 or 5 year period at Kwajalein and by the condition of the coating at Kaneohe at the same rating period. Selection of a recommended coating system can be determined by comparing the condition of the coating at both tropical test sites during the 3 to 5 year exposure period.

FINDINGS AND CONCLUSIONS

After 5 years of exposure to the tropical marine atmospheric exposure sites of Kwajalein and Kaneohe, and also at Port Hueneme, it is concluded that:

1. Two- or three-package zinc-rich epoxy coatings will satisfactorily protect a steel substrate for 4 years, even in a highly corrosive tropical atmospheric environment.

2. Early failure of an applied zinc-rich epoxy coating can occur if the zinc dust pigment is not completely dispersed when applied.

3. Early failure may occur if an aluminum-filled topcoat is applied directly over a zinc-rich primer.

4. The alkyd enamel, TT-E-489, is a satisfactory topcoat for zinc-rich epoxy primers and will perform better if applied without an intermediate primer coat.

5. The silicone alkyd (Mare Island Formula 1005, white) applied over the alkyd enamel (TT-E-489) as an intermediate coat is an exceptionally good topcoat system for a zinc-rich epoxy.

6. Epoxy or coal-tar epoxy coatings are satisfactory topcoats for zinc-rich epoxy primers.

7. The modified saran (Mare Island Formula 3F-116-1, orange and 3F-116-4, white) is an excellent coating system for a marine atmospheric environment.

8. The modified saran is superior in application ease and performance to saran, MIL-L-18389.

9. The optimum zinc loading for superior coating performance is between 3.1 and 5.3 pounds of zinc dust per gallon in the modified saran (Mare Island Formula 3F-116-1, orange).

10. The modified saran (Mare Island Formula 3F-116-1, orange) with 3 to 5 pounds of zinc dust per gallon is an excellent coating for use in a marine atmospheric environment.

11. Zinc-rich primers, in general, are superior to the red-lead primers for protecting steel in a tropical or other marine atmospheric environment.

12. Exposure data on 3 to 5 years of exposure of protective coatings in Kwajalein and Kaneohe is sufficient to determine acceptable or superior coating performance.

RECOMMENDATIONS

1. Zinc-rich epoxy primers with silicone alkyd, epoxy, or coal-tar epoxy topcoats are recommended for use in marine atmospheric environments.

2. Zinc-rich epoxy or zinc-filled modified saran primers should be considered for replacing toxic red-lead or chromate pigmented primers for use in a marine atmospheric environment.

3. A suitable high-flash solvent should be selected for the modified saran (Mare Island Formulas 3F-116-1 and 3F-116-4) to adapt it for inclusion in a specification for a coating system utilizing about 4.0 pounds of zinc dust per gallon in the primer.

4. Laboratory and field tests should be conducted to compare the performance in a marine atmospheric environment of (1) Mare Island Formulation 1005 silicone alkyd enamel topcoat with (2) TT-E-490B semigloss and MIL-E-46141 gloss specification silicone enamel topcoats. These comparison tests should be replicated with and without a tie coat (TT-E-489c) and over zinc-rich primers and chromate primers.

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Construction and Utilities, Kwajalein Missile Range

Mr. A. F. Curry of the Materials Science Division, NCEL, prepared the test specimens, assisted during their installation and inspection, and helped prepare the tables in this report.

Appendix A

RATINGS ASSIGNED COATING SYSTEMS

Ratings were assigned by NCEL personnel in accordance with ASTM standards, where applicable. A numerical rating system was used for recording the *degree of protection* given by a coating; a rating of 10 indicated complete protection, and a rating of 0 indicated no protection. For example, if the metal substrate had lost protection over 10 to 20% of its surface, the coating was given a rating of 8. For the purpose of this report, a protection rating of 7 indicated coating failure; this rating indicates that maintenance or recoating is necessary. A letter "E" in the tabulation indicates the rating relates to the edges.

Chalking is evident as a removable powder evolving from the coating film at or just beneath the surface. During the tests, chalking was determined by making a 4-inch stroke with a clean, dry cloth across the surface of the coating. Comparison of the powder spot on the cloth with photographic reference standards (ASTM Designation D659-44) made it possible to rate the degree of chalking from 10 (no powder on the cloth) to 2 (the spot on the cloth completely covered with powder). Because the amount of chalking present on the coating film at the rating time was affected by recent rainfall, the recorded rating represents a maximum value for chalking.

Degree of appearance of rusting was rated in accordance with ASTM Designation D610-43. Both Type 1 rusting, without blistering, and Type 2 rusting, with blistering, were rated.

The blister size is also designated 10 to 2; 10 indicates no blisters, 8 indicates the smallest blister easily seen with the unaided eye, and 6, 4, and 2 represent progressively larger sizes. Size 2 represents a blister diameter of about 1/8 inch or larger. The *frequency of occurrence of blisters* is reported as dense (D), medium dense (MD), medium (M), and few (F), where "dense" represents complete surface coverage, and "few" only occasional blistering. Thus, a rating of 2/M would represent blisters of 1/8-inch diameter or larger occurring over possibly one-half of the surface.

For classifying the coating systems relative to the protection they gave to the test panels, Navy alkyd (System 9) was used as a high-quality standard of comparison.

System 1

Location	Years Exposed	Unscribed Panels						Scribed Panels	
		Protection	Chalking	Blistering	Undercutting Edges	Rusting		Protection	Blistering
						Type I	Type II		
Kwajalein	1	10	10	10	10	10	10	10	10
	2	10	10	10	10	9E	10	10	10
	3	9	8	10	M/E	8E	10	8	10
	4	7	10	10	H/E	7E	10	0	10
Kaneohe	1	10	10	10	10	9E	10	10	10
	2	10	10	10	10	9E	10	10	10
	3	9+	10	10	9	8E	10	9+E	10
	4	8	10	10	9	8E	10	8E	10
	5	7	10	10	8	7E	10	7E	10
Port Hueneme-Site 1	1	10	6	10	10	10	10	10	10
	2	10	6	10	10	10	10	10	10
	3	10	8	10	10	10	10	10	10
	4	10	8	10	10	10	10	10	10
	5	10	10	10	10	10	10	10	10
Port Hueneme-Site 2	1	10	8	10	10	10	10	10	10
	2	10	8	10	10	10	10	10	10
	3	10	8	10	10	10	10	10	10
	4	10	8	10	10	10	10	10	10
	5	10	10	10	10	10	10	10	10

System 1-1

Location	Years Exposed	Unscribed Panels						Scribed Panels	
		Protection	Chalking	Blistering	Undercutting Edges	Rusting		Protection	Blistering
						Type I	Type II		
Kwajalein	1	10	10	10	10	10	10	10	10
	2	10	10	10	10	10	10	10	10
	3	8	10	10	2/DE	7E	7E	10	10
	4	7	10	2/D	H/E	7E	7E	8E	10
Kaneohe	1	10	10	10	10	10	10	10	10
	2	10	8	10	10	10	10	10	10
	3	10	8	10	10	9E	10	10	10
	4	7E	10	10	10	7E	10	7E	10
Port Hueneme-Site 1	1	10	8	10	10	10	10	10	10
	2	10	8	10	10	10	10	10	10
	3	10	8	10	10	10	10	10	10
	4	10	10	10	10	10	10	10	10
	5	10	10	10	10	10	10	10	10
Port Hueneme-Site 2	1	10	8	10	10	10	10	10	10
	2	10	10	10	10	10	10	10	10
	3	[illegible]	8	10	10	10	10	10	10
	4	10	8	10	10	10	10	10	10
	5	10	10	10	10	10	10	10	10

System 1A

Location	Years Exposed	Unscribed Panels						Scribed Panels	
		Protection	Chalking	Blistering	Undercutting Edges	Rusting		Protection	Blistering
						Type I	Type II		
Kwajalein	1	10	4	10	10	9E	10	10	10
	2	10	4	10	10	9E	10	10	10
	3	9	6	2/F	10	3E	10	8	2/MD
	4	5	8	2/M	10	5	10	4	2/D
Kaneohe	1	10	4	10	10	10	10	10	10
	2	10	6	10	10	10	10	10	10
	3	10	4	10	10	10	10	9	6/M
	4	9	6	10	10	10	10	8	2/M
	5	8-	6	E	5E	2E	4E	8-	2/MD
Port Hueneme-Site 1	1	10	6	10	10	10	10	10	10
	2	10	6	10	10	10	10	10	10
	3	10	6	10	10	10	10	10	10
	4	10	4	10	10	10	10	10	2/F
	5	10	8	10	10	10	10	10	2/F
Port Hueneme-Site 2	1	10	6	10	10	10	10	10	8/M
	2	10	6	10	10	10	10	10	8/M
	3	10	6	10	10	10	10	10	8/M
	4	10	8	10	10	10	10	10	8/M
	5	10	8	10	10	10	10	10	6/MD

System 1SC

Location	Years Exposed	Unscribed Panels						Scribed Panels	
		Protection	Chalking	Blistering	Undercutting Edges	Rusting		Protection	Blistering
						Type I	Type II		
Kwajalein	1	10	8	10	10	10	10	10	10
	2	10	8	10	10	10	10	10	4/F
	3	9	6	2/F	10	8E	9E	9	2/M
	4	8E	4	2/F	10	8E	8E	7	2/M
	5	8E	6	2/F	10	8E	8E		
Kaneohe	1	10	8	10	10	10	10	10	10
	2	10	8	10	10	10	10	10	10
	3	10	8	10	10	10	10	10	10
	4	10	8	10	10	9E	10	9	10
	5	9	6	10	8E	6E	8E	9	10
Port Hueneme-Site 1	1	10	8	10	10	10	10	10	10
	2	10	8	10	10	10	10	10	10
	3	10	8	10	10	9+E	10	10	10
	4	missing							
Port Hueneme-Site 2	1	10	8	10	10	10	10	10	10
	2	10	8	10	10	10	10	10	10
	3	10	8	10	10	9E	10	10	10
	4	10	8	10	10	9E	10	10	10
	5	10	10	10	10	9E	10	10	6/F

System 2

Location	Years Exposed	Unscribed Panels						Scribed Panels	
		Protection	Chalking	Blistering	Undercutting Edges	Rusting Type I	Rusting Type II	Protection	Blistering
Kwajalein	1	10	10	10	10	10	10	10	10
	2	10	10	10	10	10	10	10	10
	3	10	10	10	10	10	10	8-	10
	4	8	10	10	10	9	10	7	10
	5	8	10	10	10	8	10		
Kaneohe	1	10	10	10	10	10	10	10	10
	2	10	10	10	10	9E	10	10	10
	3	10	10	10	10	9E	10	10	10
	4	10	10	10	10	9E	10	10	10
	5	9	6	10	10	4E	10	10	10
Port Hueneme-Site 1	1	10	8	10	10	10	10	10	10
	2	10	8	10	10	10	10	10	10
	3	9	6	10	10	9E	10	10	10
	4	9	8	10	10	9E	10	10	10
	5	9	10	10	10	9E	10	10	10
Port Hueneme-Site 2	1	10	8	10	10	10	10	10	10
	2	10	2	10	10	10	10	10	10
	3	10	6	10	10	10	10	10	10
	4	9	8	10	10	9E	10	9	10
	5	9	10	10	10	9E	10	9	10

System 2-1

Location	Years Exposed	Unscribed Panels						Scribed Panels	
		Protection	Chalking	Blistering	Undercutting Edges	Rusting Type I	Rusting Type II	Protection	Blistering
Kwajalein	1	10	4	10	10	10	10	10	4/F
	2	10	6	10	10	10	10	10	4/M
	3	10	6	10	10	10	10	8	2/D
	4	9	8	10	10	9	10	7	2/D
	5	9	6	10	10	9	10		
Kaneohe	1	10	4	10	10	10	10	10	10
	2	10	6	10	10	10	10	[illegible]	2/F
	3	10	8	10	10	10	10	9	2/F
	4	9	8	10	10	9	10	9	2/M
	5	9	4	10	10	9	10	9	2/M
Port Hueneme-Site 1	1	10	6	10	10	10	10	10	10
	2	10	6	10	10	10	10	10	10
	3	10	4	10	10	10	10	10	10
	4	10	6	10	10	10	10	9+	10
	5	10	8	10	10	10	10	9+	10
Port Hueneme-Site 2	1	10	8	10	10	10	10	10	10
	2	10	2	10	10	10	10	10	10
	3	10	6	10	10	10	10	10	10
	4	10	6	10	10	10	10	10	10
	5	10	8	10	10	10	10	10	10

System 2A

Location	Years Exposed	Unscribed Panels						Scribed Panels	
		Protection	Chalking	Blistering	Undercutting Edges	Rusting Type I	Rusting Type II	Protection	Blistering
Kwajalein	1	10	2	10	10	10	10	9	4/MD
	2	10	2	10	10	9E	10	8	4/D
	3	10	6	10	10	9E	10	8-	4/D
	4	10	8	10	10	8E	10	8-	4/D
	5	9+	8	8E	10	6E	8E	7	4/D
Kaneohe	1	10	4	10	10	10	10	10	8/M
	2	10	6	10	10	10	10	10	8/M
	3	10	4	10	10	10	10	9-	6/M
	4	10	8	10	10	10	10	8	6/MD
	5	9	6	10	10	8E	10	8	6/MD
Port Hueneme-Site 1	1	10	6	10	10	10	10	10	10
	2	10	6	10	10	10	10	10	10
	3	9	6	10	10	9E	10	10	10
	4	9	4	10	10	9E	10	9+	10
	5	9	6	10	10	8E	10	9+	10
Port Hueneme-Site 2	1	10	6	10	10	10	10	10	10
	2	10	6	10	10	10	10	10	8/F
	3	10	6	10	10	10	10	10	8/M
	4	10	8	10	10	10	10	10	8/F
	5	10	8	10	10	10	10	10	6/F

System 2SC

Location	Years Exposed	Unscribed Panels						Scribed Panels	
		Protection	Chalking	Blistering	Undercutting Edges	Rusting		Protection	Blistering
						Type I	Type II		
Kwajalein	1	10	8	10	10	10	10	10	8/MD
	2	10	8	10	10	9E	10	10	8/MD
	3	10	6	10	10	8E	10	9	8/D
	4	9	8	10	10	6E	8E	9	8/D
	5	9	8	10	10	3E	5E	9-	8/D
Kaneohe	1	10	8	10	10	10	10	10	10
	2	10	8	10	10	9E	10	10	10
	3	10	8	10	10	9E	10	10	8/MD
	4	10	8	10	10	7E	10	9	8/MD
	5	9	8	10	10	4E	8E	9	8/MD
Port Hueneme-Site 1	1	10	8	10	10	10	10	10	10
	2	10	8	10	10	10	10	10	10
	3	9	8	10	10	9E	10	10	10
	4	9	8	10	10	9E	10	9	10
	5	9	8	10	10	9E	10	9	10
Port Hueneme-Site 2	1	10	8	10	10	10	10	10	10
	2	10	8	10	10	10	10	10	10
	3	10	8	10	10	10	10	10	8/F
	4	10	8	10	10	8E	10	10	8/F
	5	10	10	2/F	10	8E	10	10	8/M

System 3

Location	Years Exposed	Unscribed Panels						Scribed Panels	
		Protection	Chalking	Blistering	Undercutting Edges	Rusting Type I	Rusting Type II	Protection	Blistering
Kwajalein	1	10	10	10	10	10	10	10	10
	2	10	10	10	10	10	10	10	10
	3	10	10	10	10	10	10	10	10
	4	9	10	10	10	8E	10	9	2/F
	5	8-	10	10	10	6E	6E	7	4/D
Kaneohe	1	10	10	10	10	10	10	10	10
	2	10	10	10	10	10	10	10	10
	3	10	10	10	10	9E	10	10	10
	4	10	10	10	10	7E	10	10	10
	5	9	10	10	10	6E	8E	10	10
Port Hueneme-Site 1	1	10	8	10	10	10	10	10	10
	2	10	8	10	10	10	10	10	10
	3	10	8	10	10	10	10	10	10
	4	10	8	10	10	10	10	10	10
	5	missing							
Port Hueneme-Site 2	1	10	6	10	10	10	10	10	10
	2	10	6	10	10	10	10	9	2/M
	3	10	8	10	10	10	10	8	2/M
	4	10	10	2/F	10	10	10	8	2/D
	5	10	10	2/F	10	9E	10	8-	2/D

System 3-1

Location	Years Exposed	Unscribed Panels						Scribed Panels	
		Protection	Chalking	Blistering	Undercutting Edges	Rusting Type I	Rusting Type II	Protection	Blistering
Kwajalein	1	10	8	10	10	10	10	7	2/D
	2	10	8	10	10	10	10		
	3	10	8	10	10	10	10		
	4	10	8	10	10	10	10		
	5	9	8	10	10	10	9E		
Kaneohe	1	10	6	10	10	10	10	9	2/MD
	2	10	8	10	10	10	10	7	2/D
	3	10	8	10	10	10	10		
	4	9	8	10	10	9E	10		
	5	9	8	10	10	9E	9E		
Port Hueneme-Site 1	1	10	8	10	10	10	10	10	10
	2	10	8	10	10	10	10	10	10
	3	10	8	10	10	10	10	10	2/F
	4	10	8	10	10	10	10	9	2/M
	5	missing							
Port Hueneme-Site 2	1	10	8	10	10	10	10	10	2/M
	2	10	8	10	10	10	10	7	2/D
	3	10	8	10	10	10	10		
	4	10	8	10	10	10	10		
	5	10	8	10	10	10	10		

System 3A

Location	Years Exposed	Unscribed Panels: Protection	Unscribed Panels: Chalking	Unscribed Panels: Blistering	Unscribed Panels: Undercutting Edges	Unscribed Panels: Rusting Type I	Unscribed Panels: Rusting Type II	Scribed Panels: Protection	Scribed Panels: Blistering
Kwajalein	1	10	2	10	10	9E	10	10	10
	2	10	2	10	10	9E	10	10	10
	3	10	6	10	10	8E	8E	8	2/D
	4	9	6	10	10	7E	7E	8	2/D
	5	8	6	4E	10	2E	2E	7	2/D
Kaneohe	1	10	4	10	10	10	10	10	10
	2	10	6	10	10	9E	10	10	10
	3	10	6	10	10	9E	10	10	10
	4	10	6	10	10	9E	10	9	4/F
	5	9	6	10	10	6E	10	8+	4/M
Port Hueneme-Site 1	1	10	6	10	10	10	10	10	10
	2	10	6	10	10	10	10	10	10
	3	10	6	10	10	9E	10	10	10
	4	9	4	10	10	9E	10	9	10
	5	9	6	10	10	9E	10	9	10
Port Hueneme-Site 2	1	10	6	10	10	10	10	10	10
	2	10	6	10	10	9E	10	10	10
	3	10	8	10	10	9E	10	10	10
	4	10	8	10	10	9E	10	10	10
	5	10	8	10	10	9E	10	10	8/F

System 3SC

Location	Years Exposed	Unscribed Panels						Scribed Panels	
		Protection	Chalking	Blistering	Undercutting Edges	Rusting		Protection	Blistering
						Type I	Type II		
Kwajalein	1	10	8	10	10	9E	10	10	8/D
	2	10	8	10	10	9E	10	10	8/D
	3	10	6	10	10	8E	9E	9	4/D
	4	10	8	10	10	4E	9E	9	4/D
	5	9	8	10	10	2E	2E	9-	4/D
Kaneohe	1	10	8	10	10	9E	10	10	10
	2	10	8	10	10	9E	10	10	10
	3	10	8	10	10	9E	10	9+	6/M
	4	10	8	10	10	8E	10	9	4/M
	5	9	6	10	8E	6E	6E	9	4/M
Port Hueneme-Site 1	1	10	8	10	10	10	10	10	10
	2	10	8	10	10	10	10	10	10
	3	9+	8	10	10	9+E	10	10	10
	4	9+	8	10	10	9+E	10	9	10
	5	9+	10	10	10	9E	10	9	10
Port Hueneme-Site 2	1	10	8	10	10	10	10	10	10
	2	10	8	10	10	9E	10	10	4/F
	3	10	8	10	10	9E	10	10	4/F
	4	10	8	10	10	9E	10	10	2/F
	5	10	10	10	10	9E	10	10	2/F

System 3A-1

Location	Years Exposed	Unscribed Panels						Scribed Panels	
		Protection	Chalking	Blistering	Undercutting Edges	Rusting		Protection	Blistering
						Type I	Type II		
Kwajalein	1	10	2	10	10	10	10	9	4/M
	2	10	2	10	10	9E	10	9	4/M
	3	10	6	10	10	9E	10	7	2/D
	4	10	8	10	10	8E	9E		
	5	9	6	9E	10	8E	9E		
Kaneohe	1	10	4	10	10	10	10	10	8/F
	2	10	6	10	10	9+E	10	9+	8/M
	3	10	6	10	10	9+E	10	8	6/MD
	4	10	8	10		9E	10	7	2/D
	5	10	8	10		9E	10		
Port Hueneme-Site 1	1	10	6	10	10	10	10	10	10
	2	10	8	10	10	10	10	10	10
	3	10	8	10	10	10	10	10	10
	4	10	4	10	10	10	10	10	10
	5	10	6	10	10	10	10	10	10
Port Hueneme-Site 2	1	10	8	10	10	10	10	10	10
	2	10	8	10	10	10	10	10	8/F
	3	10	8	10	10	10	10	10	8/F
	4	10	8	10	10	10	10	10	2/F
	5	10	8	10	10	10	10	10	8/M

System 4

Location	Years Exposed	Unscribed Panels						Scribed Panels	
		Protection	Chalking	Blistering	Undercutting Edges	Rusting		Protection	Blistering
						Type I	Type II		
Kwajalein	1	10	10	10	10	10	10	10	10
	2	10	8	10	10	9E	10	10	10
	3	7	10	10	10	8	9	7	4/D
Kaneohe	1	10	10	10	10	10	10	10	10
	2	10	10	10	10	9+	10	10	10
	3	8-	6	10	10	8	10	8-	10
Port Hueneme-Site 1	1	10	8	10	10	10	10	10	10
	2	10	8	10	10	10	10	10	10
	3	10	8	10	10	10	10	10	10
	4	10	8	10	10	10	10	10	10
	5	10	8	10	10	10	10	9+	10
Port Hueneme-Site 2	1	10	4	10	10	10	10	10	10
	2	10	6	10	10	10	10	10	10
	3	10	8	10	10	10	10	10	10
	4	10	10	2/M	10	10	10	10	4/M
	5	9	10	2/M	10	9	10	9	4/MD

System 4-1

Location	Years Exposed	Unscribed Panels: Protection	Unscribed Panels: Chalking	Unscribed Panels: Blistering	Unscribed Panels: Undercutting Edges	Unscribed Panels: Rusting Type I	Unscribed Panels: Rusting Type II	Scribed Panels: Protection	Scribed Panels: Blistering
Kwajalein	1	10	4	10	10	9E	10	9	4/D
	2	10	6	10	10	9E	10	9	4/D
	3	10	8	10	10	7E	8E	8	2/D
	4	7E	8	10	10	3E	5E	7	2/D
Kaneohe	1	10	2	10	10	9E	10	10	8/MD
	2	10	6	10	10	9E	10	10	8/D
	3	10	6	10	10	8E	10	9	8/D
	4	10	8	10	10	7E	9E	9	8/D
	5	9E	8	10	9E	4E	6E	8	8/D
Port Hueneme-Site 1	1	10	4	10	10	10	10	10	10
	2	10	4	10	10	10	10	10	10
	3	10	4	10	10	10	10	10	10
	4	9	2	10	10	9E	10	9	10
	5	9	6	10	10	9E	10	9	10
Port Hueneme-Site 2	1	10	6	10	10	10	10	10	10
	2	10	4	10	10	9E	10	10	8/F
	3	10	6	10	10	9E	10	10	4/F
	4	9+	6	10	10	9E	10	9	4/F
	5	9+	8	10	10	9E	10	9	2/F

System 4A

Location	Years Exposed	Unscribed Panels: Protection	Unscribed Panels: Chalking	Unscribed Panels: Blistering	Unscribed Panels: Undercutting Edges	Unscribed Panels: Rusting Type I	Unscribed Panels: Rusting Type II	Scribed Panels: Protection	Scribed Panels: Blistering
Kwajalein	1	10	2	10	10	9E	10	10	4/F
	2	10	2	10	10	8E	10	9	4/M
	3	10	4	10	10	8E	9E	8	4/D
	4	10	6	10	10	6E	9E	8-	2/M
	5	9	6	10	10	6E	6E	7	2/M
Kaneohe	1	10	2	10	10	10	10	10	8/F
	2	10	4	10	10	10	10	10	8/M
	3	10	4	10	10	10	10	9+	8/M
	4	10	8	10	10	8E	10	9+	8/MD
	5	10	6	10	10	8E	10	9	8/MD
Port Hueneme-Site 1	1	10	6	10	10	10	10	10	10
	2	10	8	10	10	10	10	10	10
	3	9+	8	10	10	9+E	10	9	10
	4	9+	4	10	10	9+E	10	9	10
	5	9+	6	10	10	9+E	10	9	10
Port Hueneme-Site 2	1	10	6	10	10	10	10	10	10
	2	10	6	10	10	10	10	10	10
	3	10	8	10	10	10	10	10	8/F
	4	10	8	10	10	10	10	10	8/F
	5	10	8	10	10	10	10	10	6/F

System 4SC

Location	Years Exposed	Unscribed Panels						Scribed Panels	
		Protection	Chalking	Blistering	Undercutting Edges	.sting		Protection	Blistering
						Type I	Type II		
Kwajalein	1	10	8	10	10	10	10	10	8/F
	2	10	8	10	10	9E	10	10	8/M
	3	10	6	10	10	8E	10	9	4/MD
	4	10	6	10	10	5E	9E	9	4/MD
	5	9	6	10	10	2E	6E	9-	4/MD
Kaneohe	1	10	8	10	10	10	10	10	10
	2	10	8	10	10	10	10	10	10
	3	10	8	10	10	10	10	10	10
	4	10	8	10	10	9E	10	10	8/MD
	5	10	6	10	10	9E	9E	10	8/MD
Port Hueneme-Site 1	1	10	8	10	10	10	10	10	10
	2	10	8	10	10	10	10	10	10
	3	9+	8	10	10	9+E	10	9	2/F
	4	9+	8	10	10	9+E	10	9+	2/F
	5	9+	8	10	10	9E	10	9	2/F
Port Hueneme-Site 2	1	10	8	10	10	10	10	10	10
	2	10	8	10	10	9E	10	10	10
	3	10	8	10	10	9E	10	10	10
	4	10	8	10	10	9E	10	10	10
	5	10	8	10	10	9E	10	10	8/M

System 4A-1

Location	Years Exposed	Unscribed Panels						Scribed Panels	
		Protection	Chalking	Blistering	Undercutting Edges	Rusting		Protection	Blistering
						Type I	Type II		
Kwajalein	1	10	4	10	10	10	10	10	8/F
	2	10	2	10	10	10	10	9	4/M
	3	10	6	10	10	10	10	8	2/MD
	4	10	8	10	10	9E	10	7	2/D
	5	10	6	10	10	9E	10		
Kaneohe	1	10	2	10	10	10	10	10	10
	2	10	4	10	10	9+E	10	10	10
	3	10	6	10	10	9+E	10	9	8/M
	4	10	8	10	10	9E	10	8	6/M
	5	10	6	10	10	9E	10	8	4/M
Port Hueneme-Site 1	1	10	6	10	10	10	10	10	10
	2	10	6	10	10	10	10	10	10
	3	10	8	10	10	10	10	10	10
	4	10	4	10	10	10	10	9	10
	5	10	6	10	10	10	10	9	10
Port Hueneme-Site 2	1	10	8	10	10	10	10	10	10
	2	10	8	10	10	10	10	10	10
	3	10	8	10	10	10	10	10	10
	4	10	8	10	10	10	10	10	10
	5	10	8	10	10	10	10	10	8/F

System 5

Location	Years Exposed	Unscribed Panels						Scribed Panels	
		Protection	Chalking	Blistering	Undercutting Edges	Rusting		Protection	Blistering
						Type I	Type II		
Kwajalein	1	10	10	10	10	10	10	10	10
	2	10	10	10	10	10	10	10	10
	3	9+	10	10	10	8E	9E	8	2/MD
	4	7	10	10	10	5E	8E	4	2/D
Kaneohe	1	10	10	10	10	10	10	10	10
	2	10	10	10	10	10	10	10	10
	3	10	10	10	10	10	10	9	10
	4	9	10	10	10	8E	10	7	2/D
	5	8	6	9	10	8E	8E		
Port Hueneme-Site 1	1	10	8	10	10	10	10	10	10
	2	10	8	10	10	10	10	10	10
	3	10	8	10	10	10	10	9+	10
	4	10	8	10	10	10	10	9+	10
	5	10	8	10	10	10	10	9	10
Port Hueneme-Site 2	1	10	6	10	10	10	10	10	10
	2	10	2	10	10	10	10	10	10
	3	10	6	10	10	10	10	10	10
	4	10	8	10	10	10	10	9	10
	5	10	10	10	10	10	10	9	10

System 5-1

Location	Years Exposed	Unscribed Panels						Scribed Panels	
		Protection	Chalking	Blistering	Undercutting Edges	Rusting		Protection	Blistering
						Type I	Type II		
Kwajalein	1	10	4	10	10	10	10	9-	4/D
	2	10	4	10	10	10	10	7	2/D
	3	10	6	10	10	10	10		
	4	10	8	10	10	9E	10		
	5	10	8	10	10	9E	10		
Kaneohe	1	10	4	10	10	10	10	10	4/MD
	2	10	4	10	10	10	10	9	4/MD
	3	10	6	10	10	10	10	8-	2/D
	4	10	6	10	10	9E	10		
	5	10	8	10	10	9E	10		
Port Hueneme-Site 1	1	10	4	10	10	10	10	10	10
	2	10	6	10	10	10	10	10	10
	3	10	6	10	10	10	10	10	10
	4	10	4	10	10	10	10	10	10
	5	10	6	10	10	10	10	10	10
Port Hueneme-Site 2	1	10	6	10	10	10	10	10	8/F
	2	10	4	10	10	10	10	9	6/M
	3	10	6	10	10	10	10	9	6/M
	4	10	8	10	10	10	10	9	6/M
	5	10	8	10	10	10	10	9	4/M

System 5A

Location	Years Exposed	Unscribed Panels						Scribed Panels	
		Protection	Chalking	Blistering	Undercutting Edges	Rusting		Protection	Blistering
						Type I	Type II		
Kwajalein	1	10	4	10	10	10	10	10	4/F
	2	10	4	10	10	9E	10	9	4/MD
	3	10	6	10	10	9E	10	7	2/D
	4	10	8	10	10	8E	9E		
	5	9	8	10	10	4E	6E		
Kaneohe	1	10	2	10	10	10	10	10	10
	2	10	4	10	10	9E	10	9	2/F
	3	10	4	10	10	9E	10	8	2/M
	4	10	6	10	10	9E	10	8	2/MD
	5	9E	6	10	10	7E	10	Missing	
Port Hueneme-Site 1	1	10	6	10	10	10	10	10	10
	2	10	8	10	10	10	10	10	10
	3	9	8	10	10	9E	10	10	10
	4	9	8	10	10	9E	10	9	10
	5	9	4	10	10	9E	10	9	10
Port Hueneme-Site 2	1	10	6	10	10	10	10	10	8/M
	2	10	6	10	10	10	10	10	8/M
	3	10	8	10	10	10	10	9	6/MD
	4	10	8	10	10	10	10	9	6/MD
	5	10	8	10	10	10	10	9	6/MD

System 5SC

Location	Years Exposed	Unscribed Panels						Scribed Panels	
		Protection	Chalking	Blistering	Undercutting Edges	Rusting Type I	Rusting Type II	Protection	Blistering
Kwajalein	1	10	8	10	10	10	10	10	10
	2	10	8	10	10	9E	10	10	10
	3	10	8	10	10	8E	8E	9	2/M
	4	9	8	10	10	6E	8E	7	2/D
	5	8	8	10	10	2E	4E		
Kaneohe	1	10	8	10	10	10	10	10	10
	2	10	8	10	10	10	10	10	10
	3	10	8	10	10	9E	10	9	2/M
	4	10	8	10	10	9E	10	8	2/D
	5	10	6	10	10	8E	10	8	2/D
Port Hueneme-Site 1	1	10	6	10	10	10	10	10	10
	2	1C	8	10	10	10	10	10	10
	3	9	8	10	10	9E	10	10	10
	4	9	8	10	10	9E	10	9	10
	5	9	8	10	10	9E	10	9	10
Port Hueneme-Site 2	1	10	4	10	10	10	10	10	10
	2	10	8	10	10	9E	10	10	10
	3	10	8	10	10	9E	10	10	10
	4	10	8	10	10	9E	10	10	2/F
	5	10	10	10	10	9E	10	10	2/F

System 6

Location	Years Exposed	Unscribed Panels						Scribed Panels	
		Protection	Chalking	Blistering	Undercutting Edges	Rusting Type I	Rusting Type II	Protection	Blistering
Kwajalein	1	10	10	10	10	10	10	10	10
	2	7	10	10	10	7	10	9E	10
	3							7	10
Kaneohe	1	10	10	10	10	10	10	10	10
	2	10	10	10	10	10	10	10	10
	3	9	10	10	10	7E	10	6	2/M[1]
	4	8	8	10	8E	2E	6E		
	5	7	8	10	8E	2E	5E		
Port Hueneme-Site 1	1	10	8	10	10	10	10	10	10
	2	10	8	10	10	10	10	10	10
	3	10	8	10	10	10	10	10	10
	4	10	10	10	10	10	10	10	10
	5	10	10	10	10	10	10	10	10
Port Hueneme-Site 2	1	10	10	10	10	10	10	10	10
	2	10	10	10	10	10	10	10	10
	3	10	10	8/D[1]	10	10	10	10	8/D[1]
	4	10	10	8/D[1]	10	10	10	10	8/D[1]
	5	10	10	8/D[1]	10	10	10	10	8/D[1]

[1] Zinc bumps.

System 6S

Location	Years Exposed	Unscribed Panels						Scribed Panels	
		Protection	Chalking	Blistering	Undercutting Edges	Rusting		Protection	Blistering
						Type I	Type II		
Kwajalein	1	10	8	10	10	10	10	9	6/D[1]
	2	10	8	10	10	10	10	8	4/D
	3	10	8	10	10	10	10	7	2/D
	4	10	8	10	10	10	10		
	5	10	8	10	10	10	10		
Kaneohe	1	10	8	10	10	10	10	9	4/M[1]
	2	10	2	10	10	10	10	9	4/MD
	3	10	4	10	10	10	10	9	4/MD
	4	10	6	10	10	10	10	8	4/MD
	5	10	6	10	10	10	10	8	4/D
Port Hueneme-Site 1	1	10	8	10	10	10	10	10	10
	2	10	8	10	10	10	10	10	10
	3	10	8	10	10	10	10	10	10
	4	10	8	10	10	10	10	10	10
	5	10	8	10	10	10	10	10	10
Port Hueneme-Site 2	1	10	8	10	10	10	10	10	10
	2	10	8	10	10	10	10	10	10
	3	10	8	10[1]	10	10	10	10	10
	4	10	8	10[1]	10	10	10	10	10
	5	10	8	10[1]	10	10	10	10	10

[1] Zinc bumps.

System 7

Location	Years Exposed	Unscribed Panels						Scribed Panels	
		Protection	Chalking	Blistering	Undercutting Edges	Rusting		Protection	Blistering
						Type I	Type II		
Kwajalein	1	10	10	10	10	10	10	10	10
	2	10	10	10	10	10	10	10	10
	3	10	10	10[1]	10	10	10	10	10
	4	9	10	10[1]	10	10	10	9	2/F[1]
	5	9	10	10[1]	10	10	10	9	2/F[1]
Kaneohe	1	10	10	10	10	10	10	10	10
	2	10	10	10	10	10	10	10	10
	3	10	10	10[1]	10	10	10	10	10
	4	10	8	10[1]	10	10	10	10	10
	5	10	8	10[1]	10	10	10	10[1]	10
Port Hueneme-Site 1	1	10	10	10	10	10	10	10	10
	2	10	10	10	10	10	10	10	10
	3	10	10	10	10	10	10	10	10
	4	10	10	10	10	10	10	10	10
	5	10	10	10	10	10	10	10	10
Port Hueneme-Site 2	1	10	10	10	10	10	10	10	10
	2	10	10	10	10	10	10	10	10
	3	10	10	10	10	10	10	10	10
	4	10	10	10[1]	10	10	10	10	10[1]
	5	10	10	10[1]	10	10	10	10	10[1]

[1] Zinc bumps.

System 7S

Location	Years Exposed	Unscribed Panels						Scribed Panels	
		Protection	Chalking	Blistering	Undercutting Edges	Rusting Type I	Rusting Type II	Protection	Blistering
Kwajalein	1	10	10	10	10	10	10	10	8/MD[1]
	2	10	8	10	10	10	10	10	8/D
	3	10	8	10	10	10	10	8-	4/D
	4	10	8	10	10	10	10	7	4/D
	5	10	8	10	10	10	10		
Kaneohe	1	10	8	10	10	10	10	10	8/D[1]
	2	10	8	10	10	10	10	10	8/D
	3	10	8	10	10	10	10	9	8/D
	4	10	8	10	10	10	10	9	8/D
	5	10	8	10	10	10	10	9	8/D
Port Hueneme-Site 1	1	10	8	10	10	10	10	10	10
	2	10	8	10	10	10	10	10	10
	3	10	6	10	10	10	10	10	10
	4	10	8	10	10	10	10	10	6/F[1]
	5	10	8	10	10	10	10	10	6/F
Port Hueneme-Site 2	1	10	4	10	10	10	10	10	8/F[1]
	2	10	8	10	10	10	10	10	8/F
	3	10	8	10	10	10	10	10	8/F
	4	10	8	10	10	10	10	10	8/F
	5	10	8	10	10	10	10	10	8/F

[1] Zinc bumps.

System 8

Location	Years Exposed	Unscribed Panels						Scribed Panels	
		Protection	Chalking	Blistering	Undercutting Edges	Rusting		Protection	Blistering
						Type I	Type II		
Kwajalein	1	10	10	10	10	10	10	10	10
	2	10	10	10	10	10	10	10	10
	3	10	10	10	10	10	10	10	10
	4	10	8	10	10	10	10	10	8/F[1]
	5	10	8	10	10	10	10	9	8/F[1]
Kaneohe	1	10	10	10	10	10	10	10	10
	2	10	10	10	10	10	10	10	10
	3	10	10	10	10	10	10	10	10
	4	10	8	10	10	10	10	10	10
	5	10	8	10	10	10	10	10	10
Port Hueneme-Site 1	1	10	10	10	10	10	10	10	10
	2	10	10	10	10	10	10	10	10
	3	10	10	10	10	10	10	10	10
	4	10	10	10	10	10	10	10	2/F[1]
	5	10	10	10	10	10	10	10	2/F[1]
Port Hueneme-Site 2	1	10	10	10	10	10	10	10	10
	2	10	8	10	10	10	10	10	10
	3	10	8	10	10	10	10	10	10
	4	10	8	10	10	10	10	10	10
	5	10	8	10	10	10	10	10	10

[1] Zinc bumps.

System 8S

Location	Years Exposed	Unscribed Panels						Scribed Panels	
		Protection	Chalking	Blistering	Undercutting Edges	Rusting		Protection	Blistering
						Type I	Type II		
Kwajalein	1	10	8	10	10	10	10	8	4/D[1]
	2	10	8	10	10	10	10	7	2/D
	3	10	8	10	10	9E	10		
	4	9	8	10	10	7E	10		
	5	9	8	10	10	7E	10		
Kaneohe	1	10	10	10	10	10	10	9-	4/MD[1]
	2	10	4	10	10	9E	10	8	4/MD
	3	10	8	10	10	9E	10	7	2/D
	4	10	8	10	10	9E	10		
	5	10	8	10	10	8E	10		
Port Hueneme-Site 1	1	10	8	10	10	10	10	10	10
	2	10	8	10	10	10	10	10	10
	3	10	6	10	10	10	10	10	2/F[1]
	4	10	8	10	10	10	10	9+	2/F
	5	10	8	10	10	10	10	9	2/F
Port Hueneme-Site 2	1	10	6	10	10	10	10	9	4/M[1]
	2	10	8	10	10	10	10	9	4/M
	3	10	8	10	10	10	10	9	4/M
	4	10	8	10	10	10	10	9-	4/M
	5	10	8	10	10	10	10	8	4/M

[1] Zinc bumps.

System 9

Location	Years Exposed	Unscribed Panels						Scribed Panels	
		Protection	Chalking	Blistering	Undercutting Edges	Rusting		Protection	Blistering
						Type I	Type II		
Kwajalein	1	10	2	10	10	9E	10	8-	2/D
	2	10	2	10	10	9E	10	5	2/D
	3	9	6	10	10	9E	9E		
	4	9	8	4/FE	9E	8E	8E		
	5	missing							
Kaneohe	1	10	2	10	10	10	10	9	4/D
	2	10	4	10	10	9E	10	8	4/D
	3	10	6	10	10	9E	10	7	2/D
	4	10	6	10	10	8E	10		
	5	9E	6	10	10	6E	9E		
Port Hueneme-Site 1	1	10	6	10	10	10	10	10	10
	2	10	8	10	10	10	10	10	10
	3	10	8	10	10	9E	10	10	10
	4	10	4	10	10	9E	10	10	10
	5	10	8	10	10	9E	10	10	10
Port Hueneme-Site 2	1	10	6	10	10	10	10	10	8/F
	2	10	8	10	10	9E	10	8	2/MD
	3	10	8	10	10	9E	10	8-	2/MD
	4	10	8	10	10	9E	10	7	2/MD
	5	10	8	10	10	9E			

System 10

Location	Years Exposed	Unscribed Panels						Scribed Panels	
		Protection	Chalking	Blistering	Undercutting Edges	Rusting		Protection	Blistering
						Type I	Type II		
Kwajalein	1	10	8	10	10	10	10	8	4/D
	2	10	8	10	10	10	10	8-	2/D
	3	10	8	10	10	10	10	7	2/D
	4	10	8	10	10	10	10		
	5	10	8	10	10	10	10		
Kaneohe	1	10	6	10	10	10	10	9	4/MD
	2	10	2	10	10	10	10	8	4/D
	3	10	8	10	10	9E	10	8	2/D
	4	10	8	10	10	8E	9E	8	2/D
	5	10	8	10	10	8E	9E	8	2/D
Port Hueneme-Site 1	1	10	6	10	10	10	10	missing	
	2	10	2	10	10	10	10		
	3	10	6	10	10	10	10		
	4	10	8	10	10	10	10		
	5	10	8	10	10	10	10		
Port Hueneme-Site 2	1	10	4	10	10	10	10	9	6/MD
	2	10	8	10	10	10	10	9	4/M
	3	10	8	10	10	9+E	10	9	4/M
	4	10	8	10	10	9+E	10	9	4/M
	5	10	8	10	10	9E	10	9	

System 11

Location	Years Exposed	Unscribed Panels						Scribed Panels	
		Protection	Chalking	Blistering	Undercutting Edges	Rusting		Protection	Blistering
						Type I	Type II		
Kwajalein	1	10	8	10	10	9E	10	8	2/D
	2	10	8	10	10	8E	10	7	2/D
	3	10	8	10	10	8E	10		
	4	9	6	10	10	7E	10		
	5	9	8	10	10	7E	10		
Kaneohe	1	10	8	10	10	9E	10	10	2/MD
	2	10	8	10	10	9E	10	8-[1]	2/D
	3	10	8	10	10	9E	10		
	4	10	8	10	10	9E	9E		
	5	9+	8	10	10	9E	9E		
Port Hueneme-Site 1	1	(panel missing)							
	2								
	3								
	4								
	5								
Port Hueneme-Site 2	1	10	8	10	10	9E	10	9-	4/MD
	2	10	8	10	10	9E	10	8	4/D
	3	10	8	10	10	9E	10	8-	2/M
	4	10	8	10	10	9E	10	7	2/MD
	5	10	8	10	10	9E	10		

[1] Removed—near failure.

Appendix B

DESCRIPTION AND THICKNESS OF COATINGS TESTED AT KWAJALEIN, KANEOHE, AND PORT HUENEME

System	Coating	Color	Coats	Thickness (mils)
1	Zinc-rich polyether	gray green		
	Zinc-rich polyether		4	6.5
1-1	Aluminum-filled bituminous emulsion	aluminum		
	Zinc-rich polyether		2	3.0
	Coal-tar epoxy (amide)[1]		1	10.0
	Aluminum-filled bituminous emulsion		1	13.0
			Total	26.0
1A	Alkyd	gray		
	Zinc-rich polyether		2	3.0
	TT-E-489c alkyd enamel		3	7.0
			Total	10.0
1SC	Silicone alkyd	gray		
	Zinc-rich polyether		2	3.0
	TT-E-489c alkyd enamel		1	3.5
	Silicone alkyd enamel		2	3.5
			Total	10.0
2	Zinc-rich epoxy	gray		
	Zinc-rich epoxy (amine)[1]		3	7.5
2-1	Epoxy	gray		
	Zinc-rich epoxy (amine)[1]		1	3.5
	Epoxy (amine)[1]		3	6.5
			Total	10.0

(1) Indicates curing agent.

System	Coating	Color	Coats	Thickness (mils)
2A	Alkyd	gray		
	Zinc-rich epoxy (amine)[1]		1	3.5
	TT-E-485d rust-inhibiting enamel		2	3.5
	TT-E-489c alkyd enamel		2	3.0
			Total	10.0
2SC	Silicone alkyd	gray		
	Zinc-rich epoxy (amine)		1	3.0
	TT-E-489c alkyd enamel		1	3.0
	Silicone alkyd enamel		2	3.5
			Total	9.5
3	Zinc-rich epoxy	gray	1	3.0
	Zinc-rich modified epoxy (amide)		3	7.0
			Total	10.0
3-1	Aluminum coal-tar epoxy	aluminum		
	Zinc-rich modified epoxy (amide)		1	2.5
	Aluminum coal tar epoxy		2	11.0
			Total	13.5
3A	Alkyd	gray		
	Zinc-rich modified epoxy (amide)		1	3.5
	TT-E-489c alkyd enamel		3	6.5
			Total	10.0
3SC	Silicone alkyd	gray		
	Zinc-rich modified epoxy (amide)		1	3.0
	TT-E-489c alkyd enamel		1	3.5
	Silicone alkyd enamel		2	3.0
			Total	9.5

(1) Indicates curing agent.

System	Coating	Color	Coats	Thickness (mils)
3A-1	Alkyd	gray		
	Zinc-rich modified epoxy (amide)		1	2.5
	MIL-P-15328B pretreatment primer		1	0.5
	TT-E-485d rust-inhibiting enamel		2	4.0
	TT-E-489c alkyd enamel		2	3.0
			Total	10.0
4	Zinc-rich epoxy	gray		
	Zinc-rich modified epoxy*		3	8.0
4-1	Epoxy	gray		
	Zinc-rich modified epoxy*		1	2.5
	Epoxy		3	6.0
			Total	8.5
4A	Alkyd	gray		
	Zinc-rich modified epoxy*		1	3.0
	TT-E-489c alkyd enamel		3	6.5
			Total	9.5
4SC	Silicone alkyd	gray		
	Zinc-rich modified epoxy*		1	3.0
	TT-E-489c alkyd enamel		1	3.0
	Silicone alkyd enamel		2	4.0
			Total	10.0
4A-1	Alkyd	gray		
	Zinc-rich modified epoxy*		1	3.0
	MIL-P-15328B pretreatment primer		1	0.5
	TT-E-485d rust-inhibiting enamel		2	3.5
	TT-E-489c alkyd enamel		2	3.0
			Total	10.0

* Analysis showed conformance to MIL-P-26915A, Type I, Class A, Primer Coating, Zinc Dust Pigmented for Steel Surfaces.

System	Coating	Color	Coats	Thickness (mils)
5	Zinc-rich epoxy	gray		
	Zinc-rich epoxy (amide)		2	7.0
5-1	Epoxy	gray		
	Zinc-rich epoxy (amide)		1	2.5
	Epoxy (amide)		2	6.5
			Total	9.0
5A	Alkyd	gray		
	Zinc-rich epoxy (amide)		1	3.0
	TT-E-489c alkyd enamel		3	6.0
			Total	9.0
5SC	Silicone alkyd	gray		
	Zinc-rich epoxy (amide)		1	3.5
	TT-E-489c alkyd enamel		1	3.0
	Silicone alkyd enamel		2	4.0
			Total	10.5
6	Modified saran			
	Modified saran 3F-116-1 +10 lb zinc dust/gal	orange	3	7.5
6S	Modified saran			
	Modified saran 3F-116-1 +10 lb zinc dust/gal		2	4.0
	Modified saran 3F-116-4	white	3	3.0
			Total	7.0
7	Modified saran			
	Modified saran 3F-116-1 +5.3 lb zinc dust/gal	orange	4	7.0
7S	Modified saran			
	Modified saran 3F-116-1 +5.3 lb zinc dust/gal	orange	3	4.5
	Modified saran 3F-116-4	white	3	2.5
			Total	7.0

System	Coating	Color	Coats	Thickness (mils)
8	Modified saran			
	Modified saran 3F-116-1 +3.1 lb zinc dust/gal	orange	5	7.5
8S	Modified saran			
	Modified saran 3F-116-1 +3.1 lb zinc dust/gal	orange	4	4.5
	Modified saran 3F-116-4	white	3	3.0
			Total	7.5
9	Alkyd	gray		
	MIL-P-15328B pretreatment primer		1	0.5
	TT-E-485d rust-inhibiting enamel		2	3.0
	TT-E-489c alkyd enamel		2	4.5
			Total	8.0
10	Modified saran			
	Modified saran 3F-116-1	orange	3	2.0
	Modified saran 3F-116-4	white	3	5.5
			Total	7.5
11	MIL-L-18389 saran			
	Saran MIL-L-18389	orange	3	3.0
	Saran MIL-L-18389	white	3	3.0
			Total	6.0

REFERENCES

1. Naval Civil Engineering Laboratory. Technical Report R-557: Zinc inorganic silicate coatings, with and without topcoats, exposed to a marine atmosphere, by C. V. Brouillette. Port Hueneme, Calif., Dec. 1967. (AD 824226L)

2.———. Technical Note N-1092: Zinc rich organic coating systems exposed to a marine atmosphere, by C. V. Brouillette. Port Hueneme, Calif., May 1970. (AD 871186L)

3.———. Technical Note N-1092 Supplement: Zinc-rich organic coating systems exposed to a marine atmosphere: Three-year exposure of zinc rich saran, by C. V. Brouillette. Port Hueneme, Calif., Mar. 1971. (AD 883682L)

4. U. R. Evans and C. A. J. Taylor. "Metal-pigmented paints for the protection of steel," Institute of Metal Finishing, Transactions, vol. 39, pt. 5, Winter 1962, pp. 188-197.

5. G. R. Somerville, J. A. Lopez, and J. P. McGuigan. "Accelerated tests on zinc rich epoxy coatings for salt water service," Materials Protection, vol. 2, no. 11, Nov. 1963, pp. 58-66.

6. Naval Civil Engineering Laboratory. Technical Note N-1105: Deep ocean exposure of zinc-rich organic coatings on steel, by C. V. Brouillette. Port Hueneme, Calif., June 1970. (AD 8722[illegible])

7.———. Technical Note N-1242: Tropical exposure of paint, by C. V. Brouillette. Port Hueneme, Calif., July 1972. (AD 748185)

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